

Carbon Disulfide Emulsion
for the Control of the Root-rot
Nematode

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By E. F. Guba

Many greenhouse establishments lack the necessary means to sterilize soil with steam or hot water. Even where these methods are practiced with successful results, they are laborious and slow and require expensive equipment. This bulletin considers the merits of carbon disulfide emulsion for controlling the root-knot nematode and its use in combination with certain soil fungicides.

MASSACHUSETTS STATE COLLEGE
AMHERST, MASS.

CARBON DISULFIDE EMULSION FOR THE CONTROL OF THE ROOT-KNOT NEMATODE

By E. F. Guba, Assistant Research Professor of Botany

INTRODUCTION

Root-knot, caused by the nematode *Heterodera radiculicola* (Greef) Müll., is the most prevalent and destructive disease of greenhouse cucumber and tomato crops in Massachusetts, and the most costly to control. It is common knowledge that soil applications of steam or hot water give control; nevertheless the need for an efficient chemical control is urgent. Because of the fact that formaldehyde and acetic acid lack satisfactory nemacidal value, their use for controlling soil inhabiting fungous parasites has been largely ignored in greenhouse practice. A more extended use of these soil disinfectants in greenhouses cannot be realized in the absence of a satisfactory chemical nemacide.

The merit of carbon disulfide emulsion as a nemacide was discovered by Schaffnit and Weber (7) in Germany. Greenhouse tests by Chapman and Parker (1) in Virginia, and by Gleisberg (3) in Germany, confirmed this discovery. The work in Germany showed that the use of carbon disulfide emulsion can be relied upon to restore normal yields and at a profitable investment. Schaffnit and Weber mixed one part of soap with four parts of carbon disulfide by volume (80 per cent emulsion), and according to their recommendations each square foot of bed received 1.3 to 2.0 ounces of actual carbon disulfide. Chapman and Parker used a commercially prepared 35 per cent emulsion at a dilution of 1-50 in water, and each square foot of bed received about 0.9 ounce of actual carbon disulfide. The merit of carbon disulfide emulsion as a nemacide is thus recognized yet there has been a lack of information that would justify any recommendations to the public on the part of this Station without careful tests in local greenhouses. Information has been needed particularly concerning the best dilution of the emulsion, the rate of application, and other factors which might be expected to have an influence upon its efficiency, cost, and safety under commercial greenhouse conditions.

PRELIMINARY CONSIDERATIONS

Commercially prepared emulsions¹ containing 35 per cent and 70 per cent carbon disulfide were at first compared on a small scale. Each was diluted to make a strength of 1-50 and applied at the rate of 1 gallon to each square foot, equivalent to about 0.9 and 1.93 ounces of actual carbon disulfide. Tomato plants were set in the plots 3 days later and were allowed to grow for two months. The tomato roots in the control plot showed a bad infestation of root-knot while those in the treated plots were healthy. The results were very striking.

The cost of a 70 per cent commercially prepared emulsion at 17 cents per pound in 50-gallon drums is, however, prohibitive in practice, for it means an expense for material alone of \$0.034 per square foot or about \$1481.00 per acre. A similar homemade emulsion can be made at a cost of \$0.009 per square foot, or approximately \$392.00 per acre, excluding labor; and if effective would represent an economical method of control. Such an emulsion was prepared to contain 68 per cent carbon disulfide, 26 per cent water, and 6 per cent rosin fish oil soap (No. 9)².

¹Manufactured by I. P. Thomas & Son, Company, Philadelphia, Penn.

²Manufactured by James Good, Inc., 2111 E. Susquehanna Ave., Philadelphia, Penn.

Fresh lettuce roots with attached galls not in excess of $\frac{1}{4}$ inch in diameter were added to nematode infested soil in three 8-inch pots on November 6, 1930. Similarly, fresh tomato roots with attached galls not in excess of $\frac{1}{2}$ inch in diameter were added to another set of three pots. On that date, and 10 and 20 days later, the contents of one pot of each series was drenched with carbon disulfide emulsion of a concentration of 1-50 in water. A few days after the treatment the pots were seeded to tomatoes. The roots were examined on the following April 13 (Table 1). The freedom of the roots from nematode root-knots offered convincing and supporting evidence of the nematocidal value of carbon disulfide emulsion, and the necessary encouragement to justify further tests under commercial conditions of culture. Several experiments have been conducted over a period of three years.

TABLE 1. — CONTROL OF ROOT-KNOT NEMATODE WITH CARBON DISULFIDE EMULSION.

On November 6, 1930, 8-inch pots were filled with soil in which were embedded roots with root-knots attached; the soils were treated the same day and 10 and 20 days later, and then seeded to tomatoes.

Source of Inoculum	Date of Treatment	ROOT INFESTATION April 13, 1931	
		Treated	Not Treated
Lettuce roots.....	{ 11-6-30	Apparently none	Slight
	{ 11-16-30	Apparently none	Severe
	{ 11-26-30	Apparently none	Slight
Tomato roots.....	{ 11-6-30	Apparently none	Severe
	{ 11-16-30	Apparently none	Severe
	{ 11-26-30	Slight	Severe

GREENHOUSE EXPERIMENTS

The tests were conducted in greenhouse ground beds heavily infested with nematode where, in the absence of sterilization, the crops have proved a complete failure as the data will show. The experiments were located in the north end of one of the greenhouses of Corazzini & Company, and at the Field Station of the Massachusetts Agricultural Experiment Station in Waltham. Tomatoes were employed as the crop plant in every case.

Methods

Materials. — The materials used in the preparation of stock carbon disulfide emulsion and the quantities of each are as follows:

Material	Volume (Gallons)	Weight (Pounds)
Carbon disulfide.....	68	680
Rosin fish oil soap.....	6	54
Water.....	26	208

The exact amount of stock emulsion needed was calculated in each case according to the area of the greenhouse bed. The required amounts of soap and water were mixed together in a wooden barrel, or similar container, and stirred vigorously with a long-handled shovel. The carbon disulfide was added last, while stirring. The stock emulsion of carbon disulfide was used at various dilutions with water, as reported in each experiment. In some instances commercial 37 per cent formaldehyde and 56 per cent acetic acid were used in combination with diluted carbon disulfide emulsion in the proportion reported in the experiments.

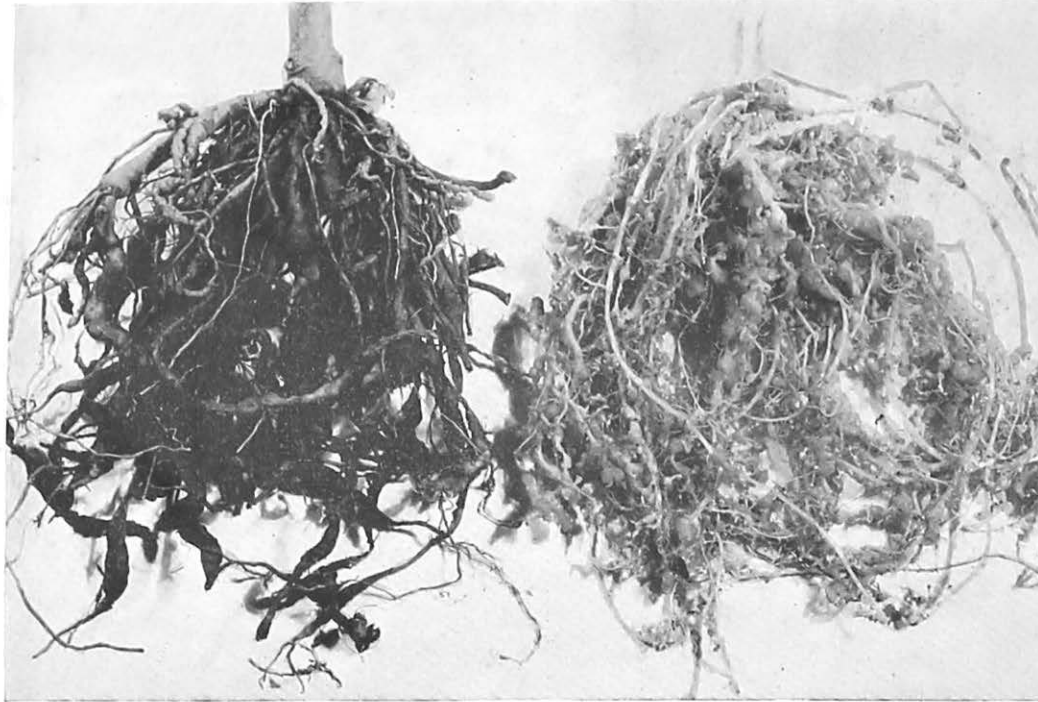


Figure 1. Tomato and Cucumber Roots Severely Infested with the Root-Knot Nematode. The knots are densely inhabited with mature female nematodes which offer a great potential increase in the nematode population of the soil. These roots should be gathered and destroyed to render sterilization more effective.

Preparation of Beds. — The larger infested roots of the old crop were removed when the plants were cleaned out, but in one instance (Table 8) these were left in the ground for comparison (Fig. 1). In most of the experiments three to four weeks elapsed after the removal of the previous crop to permit decay of the roots, but shorter intervals were used in some cases in order to determine to what extent the decay of the roots influenced the effectiveness of the chemical. If the soil was dry, it was wetted well with water a day before treatment.

Application of the Chemical. — Some of the beds were dug over and left rough and then drenched. Others were dug as the chemical was applied. The usual application was at the rate of 1 gallon of diluted emulsion to each square foot of bed, but in some instances more was applied for comparison. The thoroughness of application and penetration in the subsoil are important factors influencing the efficiency of steam or hot water methods of sterilization, and this fact was fully appreciated in the use of chemicals. Walls adjacent to the beds were also drenched. After the beds were treated they were wetted further with water.

Experiments in a Commercial Greenhouse

Spring of 1930. — Four beds were treated with carbon disulfide emulsion, to determine the effect of different concentrations of carbon disulfide emulsion on the control of the root-knot nematode and the consequent yield and income of tomatoes. The stock emulsion was used at concentrations of 1-25, 1-50, 1-75, and 1-100 gallons of water, and applied at the rate of 1 gallon to each square foot of bed. The treatments were made February 21. The roots were well decayed when the plots were spaded in preparation for the treatments.

Potted tomato plants which were grown in steam sterilized soil were set in the beds five days after the treatment. A control plot adjoined each treated plot. Careful yield records were kept. No records of root infestation were made, but examination of the roots when the plants were pulled on July 17, 1930, revealed some root infection in all the treated plots. The plants in all of the treated plots maintained a healthy, turgid growth, produced a good set, and the tomatoes were practically all of first grade. In the control plots the plants produced a poor set, and wilting, which is characteristic of a severe infestation of nematode, was very pronounced. One-half of the yield of the controls was of second grade fruit. The results clearly show the merit of carbon disulfide emulsion in eliminating the nematode as a factor in crop loss (Table 2).

TABLE 2. — EFFECT OF DIFFERENT CONCENTRATIONS OF CARBON DISULFIDE EMULSION ON THE CONTROL OF THE ROOT-KNOT NEMATODE AND THE CONSEQUENT YIELD AND INCOME OF TOMATOES

(Spring Crop, 1930. Commercial Greenhouse)

	DILUTION OF CARBON DISULFIDE EMULSION				No Treatment
	1-25	1-50	1-75	1-100	
Cost of chemical for 100 square feet.....	\$ 1.88	\$ 0.94	\$ 0.59	\$ 0.47	
Yield of 100 plants.....pounds	695	719	720	672	403
Increase in yield.....pounds	292	316	317	269	
Gross income from 100 plants at 23 cents per pound	\$159.85	\$165.37	\$165.60	\$154.56	\$64.48 ¹
Increase in gross income.....	\$ 95.37	\$100.89	\$101.12	\$ 90.08	

¹ Since approximately 50 per cent of the crop from the control plot was of second grade, the income from that plot is calculated on the basis of an average of 16 cents per pound.

Spring of 1931. — This test was conducted to compare carbon disulfide emulsion with formaldehyde and to determine the influence of different methods of applying carbon disulfide emulsion on the control of the root-knot nematode and the consequent yield and income of tomatoes. The fall planting of tomatoes was removed on January 16. The chemicals were applied on February 15. One plot received carbon disulfide emulsion as a top drench after the soil had been spaded; in another plot the chemical was applied in the furrows as the soil was being spaded. One bed was treated with formaldehyde alone. Application in each plot was at the rate of 1 gallon per square foot. The beds were planted to tomatoes on February 21. The planting was cleaned out on July 22.

TABLE 3. — COMPARISON OF CARBON DISULFIDE EMULSION WITH FORMALDEHYDE AND THE INFLUENCE OF DIFFERENT METHODS OF APPLYING CARBON DISULFIDE EMULSION ON THE CONTROL OF THE ROOT-KNOT NEMATODE AND THE CONSEQUENT YIELD AND INCOME OF TOMATOES

(Spring Crop, 1931. Commercial Greenhouse)

	CARBON DISULFIDE EMULSION 1 — 50		Formaldehyde 1 — 50	No Treatment
	Spaded In	Top Drench		
Roots free or relatively free of root-knots, per cent	85.71	72.70	50.00	1.96
Yield of 100 plants.....pounds	502	464	437	178
Gross income from 100 plants at 20 cents per pound	\$100.40	\$92.80	\$87.40	\$21.36 ¹
Increase in gross income.....	\$ 79.04	\$71.44	\$66.04	

¹ Since approximately 50 per cent of the crop from the control plot was of second grade, the income from that plot is calculated on the basis of an average of 12 cents per pound.

In this experiment, carbon disulfide emulsion was most efficient in the control of the root-knot nematode, and best yields were correlated with the best control of the pest (Table 3). An application of carbon disulfide emulsion while spading the beds, which provided the most thorough drenching of the soil, gave the best results. The check plot yielded an average of 1.7 pounds of tomatoes per plant, largely of second grade, compared with an average of 5 pounds from the best plot receiving carbon disulfide emulsion, representing a difference in gross income of 79 cents per plant. Formaldehyde showed considerable value as a nemacide.

Fall of 1931. — This experiment was conducted to determine the compatibility of formaldehyde and acetic acid with carbon disulfide emulsion, and the influence of these combinations on the control of nematode. Comparison was made with an adjacent plot which was steamed with the pan. The beds were treated on August 14 with diluted chemical at the rate of 1 gallon per square foot. The former spring crop was cleaned out July 22. The fall planting was set August 22. Records of root infestation were made on January 18, 1932 (Table 4).

A combination of 1 gallon of formaldehyde and 1 gallon of carbon disulfide emulsion in 50 gallons of water proved as effective as steam applied by the pan method in combating root-knot nematode, although a difference in yield in favor of chemical sterilization resulted. This might be explained by the fact that the chemically treated plots were favored with better pollinating and growing conditions. The addition of acetic acid to diluted carbon disulfide emulsion completely removed the soap from the emulsion which was apparently the reason why the combination was ineffective. Formaldehyde and carbon disulfide emulsion were perfectly compatible and gave complete control of the root-knot nematode.

TABLE 4. — COMPARISON OF COMBINATIONS OF CARBON DISULFIDE EMULSION AND SOIL FUNGICIDES WITH STEAM FOR COMBATING THE ROOT-KNOT NEMATODE.

(Fall Crop of Tomatoes, 1931. Commercial Greenhouse)

	Steam Pan	CARBON DISULFIDE EMULSION 1—50	
		With 1 gallon Formaldehyde	With 1 gallon Acetic Acid
Yield of 100 plants..... pounds	203	244	188
Root infestation..... per cent			
Apparently none.....	100	100	0
Slight.....	0	0	21.42
Severe.....	0	0	78.57

Spring of 1932. — This test was conducted to determine the influence of different rates of application of diluted carbon disulfide emulsion and to compare chemical with steam treatment of the soil in the control of the nematode. The roots of the previous fall crop were dug January 18, 1932, and the soil treatments were applied on February 15. Carbon disulfide emulsion, diluted at the rate of 1 gallon to 50 gallons of water, was used at different rates of application, and the treated beds were set to tomatoes February 22, 1932. Records of root infestation were taken on July 25. The best control of the root-knot nematode was obtained in the steamed plot where but 3.7 per cent of the roots were found to be infested, compared with 21.42 per cent in the plot receiving 1.4 gallons and 33.32 per cent in the plot receiving 1 gallon of diluted carbon disulfide emulsion per square foot (Table 5). In spite of these significant differences in control, the yields offered only a slight and inconsistent contrast. Since a rate of 1.4 gallons per square foot would insure a more thorough wetting and greater penetration than 1 gallon, it is inferred that thoroughness of application is an important factor contributing toward the successful control of the pest.

TABLE 5. — INFLUENCE OF RATE OF APPLICATION OF CARBON DISULFIDE EMULSION ON THE CONTROL OF THE ROOT-KNOT NEMATODE, AS COMPARED WITH STEAM.

(Spring Crop of Tomatoes, 1932. Commercial Greenhouse)

	Steam Pan	CARBON DISULFIDE EMULSION 1—50	
		1.4 gallons per square foot	1 gallon per square foot
Root infestation..... per cent			
Apparently none.....	96.29	78.57	66.66
Slight.....	2.47	19.64	11.90
Moderate.....	0	1.78	9.52
Severe.....	1.23	0	11.90
Total infestation.....	3.70	21.42	33.32
Yield of 100 plants..... pounds	668	640	657

Experiments at the Field Station

Spring of 1931. — Single and double applications of carbon disulfide emulsion were compared for their control of the root-knot nematode. A 1-50 concentration of carbon disulfide emulsion was used. The basal root clumps of the previous planting were dug out on January 30, 1931. Treatments at the rate of 1 gallon to each square foot of bed were made on February 12 and 19. The treated beds were set to tomatoes on February 26. The roots were examined on August 6

(Table 6). The single treatment with carbon disulfide emulsion proved very effective and the double treatment gave complete control of the root-knot nematode.

TABLE 6. — COMPARISON OF ONE AND TWO APPLICATIONS OF CARBON DISULFIDE EMULSION FOR CONTROLLING THE ROOT-KNOT NEMATODE.

(Spring Crop of Tomatoes, 1931. Field Station)

	CARBON DISULFIDE EMULSION 1 — 50		No Treatment	
	I — One Application	II — Two Applications	I	II
Root infestation..... per cent				
Apparently none.....	95.71	100	0	0
Slight.....	0	0	67.30	62.50
Severe.....	4.29	0	32.39	37.50
Yield of 100 plants..... pounds				
Ones.....	735	863	654	360
Seconds.....	293	329	301	265
Total.....	1028	1192	955	625

Fall of 1931. — The purpose of this test was to determine whether successful control of nematode on one crop, resulting from the use of carbon disulfide emulsion (Table 6), could be relied upon to provide control for the succeeding crop. The plots of the previous experiment were again planted to tomatoes on August 24. The plots were not sterilized, but the roots of the previous crop were cleaned out well, and the top soil to a depth of 6 inches was removed. Records of root infestation were taken on January 19, 1932. In spite of the removal of the roots and the soil, and the fact that excellent control of nematode was obtained on the previous spring crop, a severe infestation developed in the fall planting (Plot B, Table 7). The results show that the eradication of nematode in greenhouse soils cannot be obtained with this chemical and that soil treatments must be repeated previous to each crop in order to realize a profitable yield. Steam or hot water methods of sterilization are no exception. Eradication has never succeeded in commercial practice with the most efficient methods of steaming, and there is no reason to expect better results from chemicals.

TABLE 7. — RELATION OF THE DEGREE OF CONTROL OF ROOT-KNOT WITH CARBON DISULFIDE EMULSION ON ONE CROP TO INFESTATION OF THE SUCCEEDING CROP

(Spring and Fall Crops of Tomatoes, 1931. Field Station)

	SPRING CROP		FALL CROP	
	Plot A No Treatment	Plot B Carbon Disulfide Emulsion	Plot A No Treatment	Plot B
	1 application.			
Root infestation..... per cent				
Apparently none.....	0	95.71	0	0
Slight.....	67.60	0	25.0	10.93
Severe.....	32.39	4.29	75.0	89.06
	2 applications			
Apparently none.....	0	100	0	34.83
Slight.....	62.50	0	16.85	24.72
Severe.....	37.50	0	83.14	40.44

Spring of 1932. — In this set of experiments the influence of different rates of application of carbon disulfide emulsion and the effect of removing the roots on the control of the root-knot nematode were studied. The old tomato vines with attached root clumps of the previous planting were removed on January 20. In two of the three beds the smaller roots were carefully removed as the beds were spaded, and in the third they were allowed to remain.

The beds were treated on January 21, 1932, with carbon disulfide emulsion of a 1-50 strength to which formaldehyde was added at the rate of 2/3 gallon to each 50 gallons of diluted emulsion. Treatments were at the rate of two and one gallons per square foot. The beds were set to tomatoes on January 29. The roots were examined for root-knot on June 24 (Table 8).

No yield records were taken, but none of the plants showed evidence of weakness or failure to set during the growing period nor was the grade of tomatoes affected. Infestation was not severe enough to affect the growth or yield. Two gallons of carbon disulfide emulsion per square foot gave better control than one gallon; but like the previous experiment one gallon per square foot removed the nematode as a crop loss factor even when the smaller infested roots were left in the beds (Table 8).

TABLE 8. — INFLUENCE OF THE RATE OF APPLICATION OF CARBON DISULFIDE EMULSION AND THE EFFECT OF ROOT REMOVAL ON THE CONTROL OF THE ROOT-KNOT NEMATODE.

(Spring Crop of Tomatoes, 1932. Field Station)

	ROOTS REMOVED ON SPADING		ROOTS NOT REMOVED
	2 gallons per square foot	1 gallon per square foot	1 gallon per square foot
Root infestation.....per cent			
Apparently none.....	92.0	31.6	16.9
Slight.....	4.8	36.6	70.7
Moderate.....	3.2	26.6	12.3
Severe.....	0	5.0	0
Total infestation.....	8.0	68.2	83.0

Discussion

The experimental results show that carbon disulfide emulsion is an effective nematocide and if used properly can be relied upon to eliminate nematode as a serious factor in crop losses. Tomato plants were used exclusively in these experiments and this fact strengthens the case for carbon disulfide emulsion, since according to Jones (5) the nematode gall of the tomato plant offers greater protection to its nematode population than that of the cucumber or lettuce plant, and in addition bears the resistant "cyst" stage. It is logical to believe, therefore, that carbon disulfide would offer better control when following crops of lettuce or cucumbers than when tomatoes have preceded treatment.

In the experiments reported, the root clump of each plant was dug out of the soil when the old vines were removed from the greenhouse as a means of assisting or rendering more effective the action of the chemical and of reducing the potential nematode population of the soil (Fig. 1). Observations and experiments show, however, that this practice alone offers no control of nematode. Naturally, the smaller infested roots were left behind, but judging from the results in Table 1, carbon disulfide emulsion is apparently nematocidal to small, fresh galls. Soil heating with steam or hot water would appear to be superior to chemicals in its nematocidal effect, especially if the galls possess much root covering tissue. Obviously, the removal of such galls before sterilization should assist materially in the control

of the nematode. It is shown (Table 8) that where the smaller infested roots were left in the soil and carbon disulfide was used at the rate of 1 gallon per square foot, 83 per cent of the roots were infested as compared to 68.2 per cent where the roots were removed. Considered on the basis of the degree of infestation, it could not be shown that the removal of the smaller roots improved the efficiency of the treatment in this experiment.

Nevertheless, judging from the results with carbon disulfide emulsion in commercial practice, the removal of the infested roots and the decay of the smaller roots and attached galls appears to be desirable as a matter of insuring greater efficiency of the chemical. According to Jones (5) galls attached to roots require more time to decay than detached galls. The rate of decay of galls is increased with increases in soil moisture and temperature. In view of this fact, it is desirable to keep the greenhouse beds moist by daily waterings, and as warm as possible between the interval of removing the old plants and the time the chemical is applied. The results of the writer's experiments show good control of nematode with carbon disulfide emulsion applied three weeks after the removal of the old planting without introducing the needed moisture and temperature conditions to hasten decay of the roots in that interval. One more week elapsed before the new planting was started. Good control of nematode was obtained when one day elapsed between the removal of the old crop and the application of carbon disulfide emulsion (Table 8) but this was influenced measurably by the rate of application.

Nematodes exist as deep in the soil as the roots extend, and it is not uncommon to find lettuce, cucumber, and tomato roots 30 inches deep in the subsoil. In Florida, the root-knot nematode may be found at a depth of 36 inches, according to Godfrey (4), and in greenhouses they occur fully as deep. Any treatment used to sterilize the soil must be applied with the object of reaching the majority of nematodes or the effectiveness of the treatment will be greatly diminished. The thoroughness of wetting the soil with chemical has a significant influence upon its effectiveness as is borne out in Table 6 where it is shown that two applications of carbon disulfide emulsion applied a week apart gave complete control, while after one treatment 95.71 per cent of the roots were free from infestation. A greater volume of chemical in one application is also more effective, for 1.4 gallons of diluted carbon disulfide emulsion per square foot yielded 78.57 per cent roots free of infestation, as compared to 66.66 per cent from 1 gallon (Table 5); and 2 gallons gave 92 per cent clean roots as compared to 31.6 per cent from 1 gallon (Table 8). In no instance, however, when the rate of application was 1 gallon per square foot, was nematode a factor in crop loss. At that rate of application, increases in gross income of \$90.08 to \$101.12 (Table 2) and of \$71.44 to \$79.04 (Table 3) were obtained per 100 plants above that of the same number of plants in the control plots.

The yields from the use of carbon disulfide emulsion were essentially similar to those where efficient steaming was practiced, and this, in general, was correlated with the degree of control of the root-knot nematode. Since a concentration of 1-50 of carbon disulfide emulsion applied at the rate of 1 gallon per square foot has given good control and has restored normal yields, this formula is recommended for those growers who desire to use this chemical.

Carbon disulfide emulsion has given satisfactory results when tested under commercial conditions of culture for combating nematode. Its use, however, has given no control of soil inhabiting plant pathogenes; neither according to the writer's experiments, has it manifested any killing effect on weed seeds. For the control of soil-borne plant pathogenes in greenhouses, the use of formaldehyde has heretofore received some recognition. Doran (2) has shown a similar value from

acetic acid at less expense. Each was used in combination with carbon disulfide emulsion, but only formaldehyde made an effective and compatible combination (Table 3). Judging from the results shown in Tables 3 and 4, formaldehyde may be regarded as having considerable nemacidal value, but acetic acid none. These results appear to be confirmed by the reports of Watson (8, 9) to the effect that formaldehyde when applied in the dosage ordinarily used for the control of fungous diseases gives very good control of the root-knot nematode in seed beds in Florida. Observations of its use in greenhouses in Massachusetts show that alone it does not offer satisfactory control of nematode, although the results in Table 3 are exceptional. In some of the experiments a concentration of 1 gallon of formaldehyde in combination with 1 gallon of stock carbon disulfide emulsion in 50 gallons of water was employed; but successful control of soil inhabiting fungous parasites can be obtained at a concentration of $\frac{2}{3}$ gallon of formaldehyde, as has been brought out from the results of many tests at the Field Station.

To qualify as a good nemacide, a chemical must be (a) effective in eliminating the nematode as a crop loss factor, (b) harmless to the soil for plant growth within a reasonable interval after application, (c) easy to apply, and (d) non-injurious to man. Of over thirty chemicals tested by Newhall (6), many of which had been previously considered in earlier investigations, none was entirely satisfactory being objectionable chiefly on account of cost, inefficiency, and unsatisfactory methods of application. Newhall found that pure carbon disulfide used at the rate of 100 gallons per acre was almost as good as the best chemical treatment, i. e., a mixture of naphthalene flakes and Cyanogas, on the basis of plant yields. He did not use carbon disulfide emulsion.

On the basis of the writer's experience and that of most growers, the objections to the chemicals used by Newhall should not necessarily apply to carbon disulfide emulsion. However, carbon disulfide possesses that disadvantage of being harmful to man. Prolonged exposure to the gas causes severe headache, dizziness, and vomiting. It increases the heartbeat, and owing to this effect persons having any heart weakness are cautioned not to use it. Otherwise, application is practical, quicker, and under many conditions less expensive than steam sterilization. The harmful features may be largely overcome by the exercise of certain precautions such as shifting the help at the end of five hours, and taking care to provide all the ventilation possible.

Once an infestation of the root-knot nematode appears, its eradication seems impossible no matter how efficient the soil treatment. In spite of the complete absence of visible signs of root-knot at the end of a crop, sufficient potential infection to cause a heavy root infestation and a yield failure on the succeeding crop escapes the action of heat or chemicals (Table 7). Where the practice is to grow two warm temperature crops such as cucumbers or tomatoes each year, the greenhouse beds must be treated before each crop, otherwise the root-knot disease will render unprofitable any investment in the crop. For this reason, it would be more economical in the end to install the permanent tile system of steam sterilization if the greenhouse establishment is permanent and if steam is available, since the expense for chemicals equals a substantial part of an investment in a tile installation. If the use of chemical is objectionable on account of its harmful effect upon men, then sterilization by the use of steam or hot water is advisable.

Carbon disulfide emulsion appears to be the most satisfactory chemical nemacide yet discovered and should find particular use in greenhouse establishments not equipped with efficient systems of steam or hot water sterilization, or where the grower for lack of time finds it more practical and desirable to use chemicals instead of steam or hot water. On the basis of the results here reported, many

growers have used carbon disulfide emulsion on a commercial scale. Their results have been very satisfactory in some instances and very disappointing in others. The most important factors contributing to the poor results have been lack of thoroughness of application and failure to remove the larger infested roots of the old planting when cleaning out the beds, and subsequently to allow time enough for the smaller roots to decay before treatment. The results of the writer's experiments show that the success of carbon disulfide emulsion as a nematocide depends chiefly upon the removal of the old roots and the thoroughness of application. Unless these requirements can be complied with in commercial practice, the use of chemicals is a futile and wasteful expense.

RECOMMENDATIONS

If the grower desires, or is obliged to resort to, chemical soil treatments he should first decide on the choice of materials. If nematode is the only crop loss factor, carbon disulfide emulsion should be used at a concentration of 1 gallon of stock to 50 gallons of water. If fungous diseases alone are responsible, formaldehyde should be used at a concentration of 2/3 gallon to 50 gallons of water. If both fungous diseases and nematode root-knot are factors contributing to the failure of the crop, formaldehyde (2/3 gallon) and carbon disulfide emulsion (1 gallon) should be used in 50 gallons of water. Application should be at the rate of 1 gallon of diluted chemical to each square foot of bed. At this rate of dilution and application, the expense for chemicals used to sterilize 10,000 square feet would be about as follows:

Carbon disulfide emulsion, alone....	\$90.00
Formaldehyde, alone.....	70.00
Carbon disulfide emulsion and formaldehyde combined.....	160.00

To calculate the number of gallons of carbon disulfide emulsion needed, the area to be sterilized is divided by 50. This quotient is multiplied by .68 and the product obtained is the number of gallons of carbon disulfide required. To convert gallons to pounds, multiply by 10. The quotient obtained by dividing the area by 50 is multiplied by .06, and the result obtained is the number of gallons of rosin fish oil soap required. This result is multiplied by 9, representing the weight in pounds of each gallon of soap, to obtain the number of pounds of soap needed. To calculate the number of gallons of formaldehyde needed, the area to be sterilized is divided by 75 and the result is multiplied by 8, representing the weight in pounds of each gallon of formaldehyde. Since the chemicals are sold by weight only, it is necessary to know the number of pounds of each required when giving the order.

Preparation of the Beds for Treatment

The roots of the previous planting should be carefully cleaned out and destroyed, and the beds should be kept moist by frequent watering for at least two weeks to assist in the decay of the smaller roots in the soil. Since fresh roots are likely to offer protection to the nematodes against the action of chemical, some decay of the roots is considered desirable before the soil is treated. It is a rather common practice in Massachusetts greenhouses to grow crops of lettuce or radish in the fall and early winter months. The low growing-temperatures for these crops inhibit the activity of the nematode, and root infestation is usually either lacking or not important enough to warrant soil sterilization. In such a rotation of crops, it would be best to delay the use of chemical until 7 to 10 days before planting the spring crop of cucumbers or tomatoes.



Figure 2. Drenching Greenhouse Beds with Carbon Disulfide Emulsion as the Soil is Being Spaded. This is the ideal method of application. It insures both thoroughness and penetration. On a small scale the chemical is diluted in 50-gallon barrels and applied with pails.

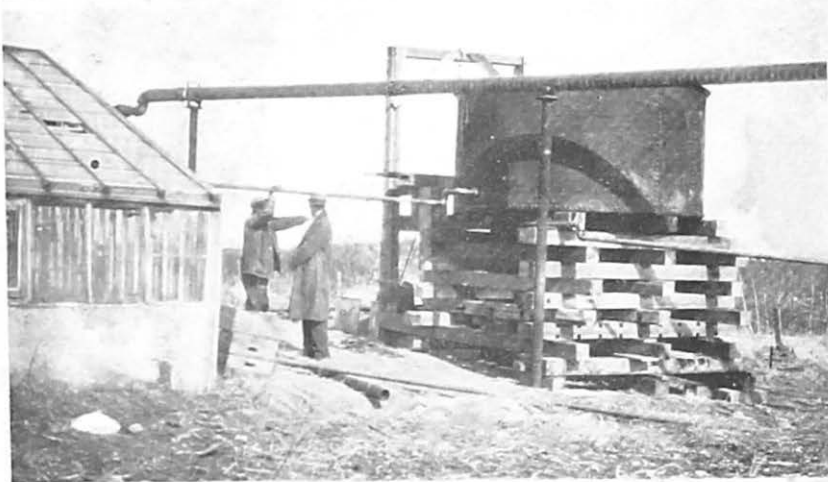


Figure 3. On a Large Scale it is More Practical to Prepare Large Quantities of the Chemical and Either Pump or Gravitare it into the Greenhouse. Some means must be provided for agitating the diluted chemical. Top: Tank of 5500 gallon capacity; Middle: Tank of 3000 gallon capacity; Bottom: Unsatisfactory method of application. The chemical runs off to the low level and puddles. It should be applied while the soil is being spaded.

Preparation of Carbon Disulfide Emulsion

A stock emulsion of carbon disulfide is prepared by first mixing together the required amount of soap and water, then adding the carbon disulfide. The water should not be cooler than 60° F.; otherwise the soap will not readily dissolve. Any amount of stock emulsion can be made by multiplying the total number of gallons wanted by .26, .06, and .68, the results representing water, soap, and carbon disulfide in gallons, respectively. Thus, to make a 50-gallon barrel of stock emulsion, 13 gallons of water, 3 gallons of soap, and 34 gallons of carbon disulfide are required.

Application of Chemicals

One gallon of stock emulsion is added to 50 gallons of water and stirred, and this diluted emulsion is applied at the rate of 1 gallon to the square foot of bed. If formaldehyde is warranted, 2/3 gallon is added to each barrel of diluted emulsion. If the chemicals are diluted in barrels, pails are used to apply the solution (Fig. 2). If a large tank is used, the solution may be run out into the beds by gravity through lines of hose, or by pressure through an irrigation system (Fig. 3). The solution must be agitated frequently.

The volume of the tank must be known in order to determine the number of gallons of concentrated chemicals needed to make the proper strength. The volume of a cylindrical tank in cubic feet is determined by multiplying .7854 by the square of the diameter of the tank and this result by the height. The volume of a rectangular tank is determined by multiplying the width by the length by the height. In either case, the result is then multiplied by 7.5 (representing the number of gallons contained in 1 cubic foot), to obtain the capacity of the tank in gallons. Since a 1-50 concentration of carbon disulfide is to be used, the capacity of the tank is divided by 50. The result represents the number of gallons of stock carbon disulfide emulsion needed. If formaldehyde is used alone or in combination with carbon disulfide emulsion, the volume of the tank is divided by 75 (2/3-50 or 1-75) and the result represents the number of gallons of formaldehyde needed.

Treatment should begin in the far end of the greenhouse. The soil should be in a moist condition and the beds should be dug over as the chemical is applied to insure thorough soaking of the soil. It may be convenient to treat the soil in sections corresponding to the areas between posts. The number of barrels of chemical required is determined and this amount is used for each section in the greenhouse. After the house has been treated in the manner described, the beds should be wetted further with water. If carbon disulfide alone is used, the beds may be planted in 6-7 days. If formaldehyde is used, an interval of 10 days may be necessary, especially in cold weather. The safety of the beds for planting may be determined by setting out a few plants; if the plants manifest no sign of injury after 24 hours, the beds should be safe to plant.

Caution

Prolonged exposure to the carbon disulfide gas causes severe headache, dizziness, and vomiting. It increases the heartbeat, and therefore persons having any heart weakness are cautioned not to use it. The harmful features may be overcome by shifting the help at the end of five hours, or by engaging the help for not more than five hours each day until the work is completed. The men should be cautioned to provide all available greenhouse ventilation during application. Cool circulating air furnishes a more desirable atmosphere than warm, stagnant air. The stock emulsion of carbon disulfide should be located outdoors or in a well-ventilated spot in the greenhouse, and the men should be cautioned to avoid its

vapors as far as possible. The pure chemical is highly inflammable and explosive and for this reason the men should be cautioned against smoking or lighting matches when using it.

SUMMARY

In greenhouses, soil treatments with carbon disulfide emulsion have given good control of the root-knot nematode and have restored normal yields. A stock emulsion containing 68 per cent carbon disulfide, 26 per cent water, and 6 per cent rosin fish oil soap was diluted in water to make a 1-50 concentration and applied to the soil at the rate of 1 gallon per square foot.

The cost for chemical materials is approximately nine-tenths of a cent per square foot.

Where soil inhabiting fungous pathogenes are also present, the addition of 2/3 gallon of formaldehyde to the above formula is recommended.

Removal of the infested roots when the houses are cleaned out, decay of root material remaining, and thoroughness of application contribute much to the effectiveness of carbon disulfide emulsion in controlling the root-knot nematode. A delay of at least 2 to 3 weeks after the old crop is cleaned out before treatment, during which interval the beds are kept moist and warm, assists in the decay of the old roots. A further delay of one week after treatment is necessary before planting.

Exposure to carbon disulfide for more than five hours at one time may cause illness and this is an objection to its use. Suggestions are offered for avoiding this danger.

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